

PROPERTIES OF ALLOY 4201 AT ELEVATED TEMPERATURES

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16. Abstract Alloy 4201 was investigated at elevated temperatures using various types of equipment for testing its strength, elastic modulus, creep, etc. both in rod and sheet specimens. The impact strength is reduced at temperatures of 1000° and 1200° due to the increase of the grain caused by intensive recrystallization processes of the alloy. In view of this and other changes which occur, these features must be taken into account when using semi-finished products in assemblies and designating values of permissible stresses.			
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To develop works [1, 2] into the research of properties of alloy 4201 (titanium with 32-35% molybdenum), the present work studied some principles for the change of its mechanical characteristics at elevated temperatures. All the research was conducted on rod and sheet material ($h = 4$ mm) of industrial batches, the chemical composition of which (in percent) is shown below. /93*

All the specimens from the sheet material were tested in their initial state (vacuum annealing at 850° , aging for one hour, furnace cooling to 400° , then in the air). The forged rods were previously annealed at 850° for one hour with air cooling. According to microstructure analysis information, specimens of the 4201 alloy (from rod and plate), before testing, had a solid solution polyhedral structure based on a body-centered lattice of β -titanium and molybdenum. /94

The research method. Specimens were produced from type KRZ (1_{eff} -- 38 mm, diameter 4 mm). The specimens were tested for expansion on a ZsF-2 tensile-testing machine with the grips moving at a rate of 6 mm/min. Some of the specimens were tested in a vacuum (residual pressure 10^{-4} mmHg) on a HBF-303 machine at 800 - 1200° with the grips moving at a rate of 2 mm/min. The sheet specimens ($1_{\text{eff}} = 5.65\sqrt{F_0}$) were tested under the same conditions at room and elevated temperatures after similar thermal treatment. The impact strength of the 4201 alloy was studied on the MK-30 pendulum hammer, equipped with an attachment for keeping the specimen heated to the required temperature semiautomatically.

*Numbers in the margin indicate pagination in the foreign text.

The impact strength was determined on standard Menage specimens at temperatures of 20 to 1200°.

The elastic modulus of the 4201 alloy was determined by the dynamic method on an "elastomat" machine produced by the Förster firm in the temperature interval of 20-600°. The elastic moduli were measured during longitudinal and lateral oscillation excitation in a specimen with a diameter of 10 mm and a length of 100 mm. The specimen was heated in air. The hardness of the alloy at elevated temperatures was measured on a VIM-1 machine in a vacuum (residual pressure 10^{-4} mmHg) in temperatures from 20 to 1100° at aging of 1, 10 and 40 min for each temperature. The loading was 1 kgf. A specimen was produced from a rod in the form of a washer with a diameter of 15 mm and a height of 5 mm.

Tests for long-time strength and creep from specimens of a rod and sheet of 4201 alloy were done on Zst 3/3 and YaB/1M machines at temperatures of 200, 400, 600, 800, and 1000° in accordance with GOST [All-Union State Standard] 10145-62. Sheet specimens were also tested for long-time strength in a vacuum (residual pressure 10^{-4} mmHg) at temperatures of 800 and 1000° (a TV-3012 machine). Sheet specimens for tests for short-term and long-time strength were identical. Fatigue tests were done in an MVP-10,000 machine. The method for loading the specimen was pure bending with rotation. The loading frequency was 5000 cycles/min. The testing temperature was 20 and 600°.

Results of research. Information obtained during short-term tests of rods and sheets of the 4201 alloy for expansion and impact resistance are shown in Fig. 1, a, b. Figure 1 also shows the results of similar research conducted in a vacuum. Analysis of curves of Fig. 1 a, b shows that the absolute strength and yield limit decrease most in temperature intervals of 20-200 and 600-1200°, and least in the temperature interval of 200-550°. These uniformities are seen more clearly when testing sheet material.

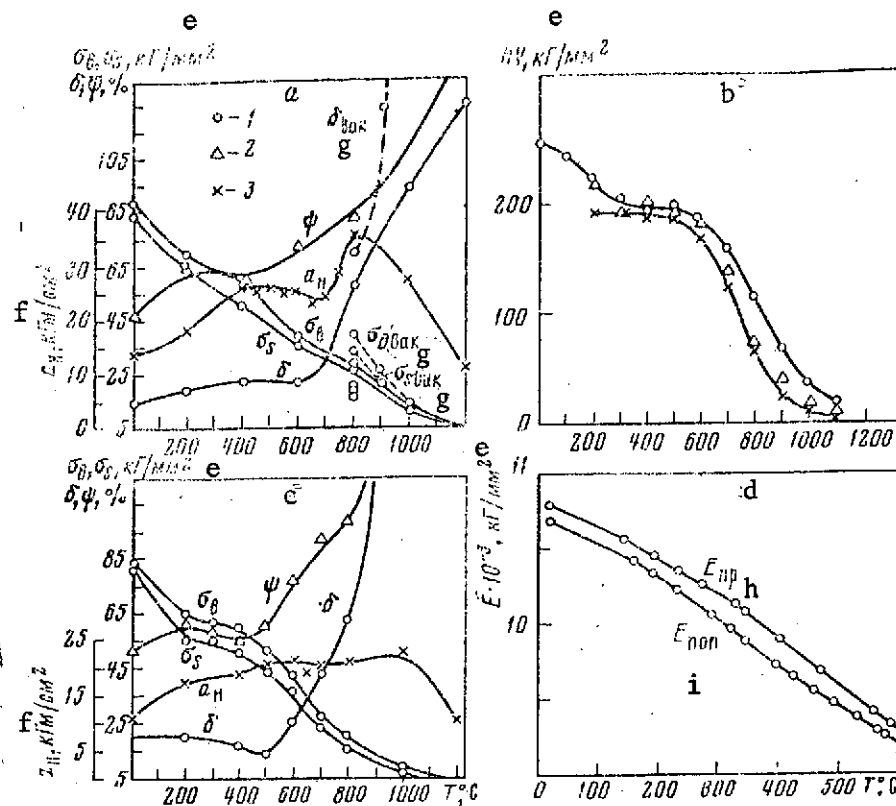


Fig. 1. The effect of the test temperature on the mechanical properties of rod material (a), the mechanical properties of sheet material (b), the hardness of the alloy (c), and the elastic modulus (d). Aging, minutes: 1 - 1; 2 - 10; 3 - 40.

Key: e. kgf/mm²
 f. kg-m/cm²
 g. vacuum
 h. longitudinal
 i. lateral

Plasticity characteristics (δ , ψ) vary in accordance with a certain reduction of them at temperatures of 400-500° in sheets and a reduction of the growth rate in rods. The impact strength of rod material changes according to the curve with a maximum at a temperature of 800°; in the temperature range of 400-700°, the value of a_H remains practically constant; its minimum value is at 650-700°. The reduction of the impact strength at temperatures of 1000, and especially at 1200°, is linked with the considerable increase of the grain, caused by the intensive processes of alloy recrystallization.

The impact strength of sheet material changes more smoothly /95 with the increase of temperature. In the interval of 500-600°, the value of a_H is practically constant (a small drop at 650-700°). At 1200°, the impact strength, as in the rod material, is reduced to values corresponding to room temperature. Another feature is the higher values of the ultimate strength and the relative elongation of specimens tested in a vacuum at a temperature of 800°, and especially the relative elongation at 1000 and 1200° (see Fig. 1, a). Probably, this is the result of different test conditions of specimens ($v = 6$ and 2 mm/min).

As can be seen from Fig. 1, c, the hardness of the alloy /96 changes with the increase of temperature similarly to the ultimate strength. In temperatures from 200- 600°, it is practically unchanged, and depends little on the length of aging. The nature of change of the ultimate strength, hardness, impact strength and plasticity characteristics (δ , ψ) in temperatures of 400-650° was observed earlier by us [1] during similar tests of experimental batches of 4201 alloy. We linked this phenomenon with the presence of a polymorphic $\beta \rightarrow \alpha$ -transformation, the temperature of which in alloy 4201 was approximately 450-650°. The elastic modulus of alloy 4201 continually decreases with the increase of the test temperature (see Fig. 1, d) from 10,800 kgf/mm² at 20° to 9300 kgf/mm² at 600°.

Figure 2, a shows curves of long-time strength of sheets at 200, 400, 600 and 800°. One should note the low rate of weakening of the metal at test temperatures of 200 and 400°. At temperatures of 600 and 800°, the angle of slope of the curves is greater -- the weakening of the metal occurs more rapidly; however, the ultimate long-time strength for 100 hours is $\sigma_{100}^{600} = 21.5$ and $\sigma_{100}^{800} = 2.5$ kgf/mm². Comparative tests of specimens from sheet 4 mm thick and rolled rod 14 x 14 mm at 600° showed that the rod had greater strength. As the temperature was further increased, the specimens oxidized considerably, and at 1000°, the metal is weak. The table shows

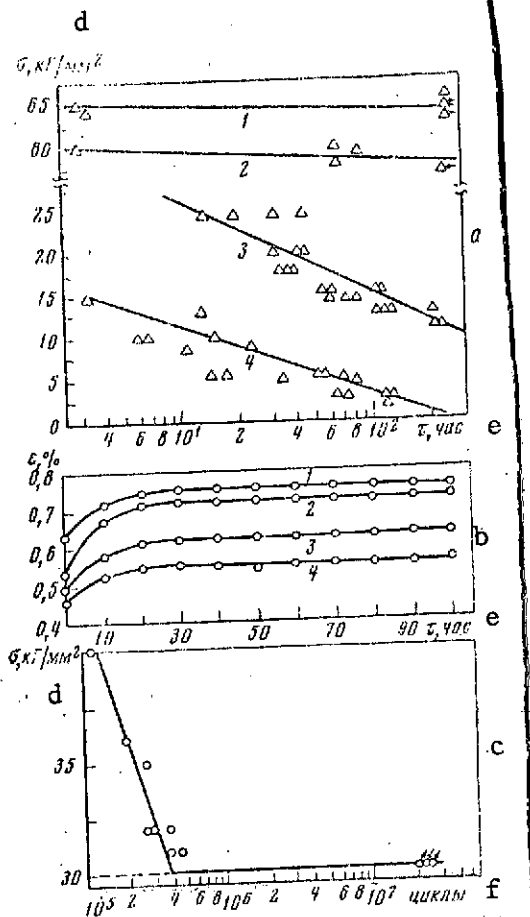


Fig. 2. Creep limit curves of the alloy (a), creep at a temperature of 200° (b), and fatigue strength at a temperature of 20° (c). a. T, °C: 1 - 200; 2 - 400; 3 - 600; 4 - 800; b. σ , kgf/mm²: 1 - 56; 2 - 55.5; 3 - 55; 4 - 54.5.

Key: d. kgf/mm²; e. hours;
f. cycles

causes a decrease in the durability of specimens.

Figure 2, b shows curves for the creep of forged rods at 200°. The creep limit for 100 and 1000 hours with a residual deformation of 0.2% is $\sigma_{0.2/100}^{200} = 55$ and $\sigma_{0.2/1000}^{200} = 52$ kgf/mm². Tests of specimens at a temperature of 600° gave $\sigma_{0.2/100}^{600} = 4.5$ kgf/mm². Figure 2, c shows the results of tests of forged rods for fatigue strength. The fatigue strength of the metal on a

the comparative results of testing alloy specimens in atmospheric conditions in a vacuum at temperatures of 800 and 1000°.

It can be seen from the table that there is a divergence between the results of tests in both media. At 800°, this divergence is small, and, apparently, is linked with the hardening of the alloy by interstitial impurities during tests in the air, in conditions when there is no weakening of the specimen cross section due to the formation of oxide films. Probably, at 1000° there is an overwhelming tendency for the formation of films with a weakening of the cross section, which

COMPARATIVE RESULTS OF TESTING SPECIMENS IN ATMOSPHERIC
CONDITIONS AND IN A VACUUM.

T, °C	σ , kgf/mm ²	Time before destruction	
		Vacuum	Air medium
800	15	2 hr 15 min	3 hr 20 min
	43	46 hr 20 min	65--75 hr
	2	67--680 hr	110 hr
1000	2	17 hr 32 min--35 hr 50 min	—
	1,5	—	4 hr 30 min
	1	42 hr 20 min--60 hr 15 min	11 hr 45 min
	0,6	582 hr	—
	0,5	—	19 hr 35 min

base of $2 \cdot 10^7$ cycles is at 20° $\sigma_{-1} = 30$ kgf/mm². Tests conducted /97
at 600° gave fatigue strength of $\sigma_{-1} = 29$ kgf/mm². Cut specimens
tested for short-term and long-time static strength showed the
insensitivity of the metal to stress concentration, whereas the
vibration sensitivity of cut samples was reduced by approximately
30%. These features of the change of the strength characteristics
of the alloy must be taken into account when using semifinished
products in assemblies and designating the values of permissible
stresses.

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